[Proc. Roy. Soc. Victoria, 52 (N.S.), Pt. II., 1940.]

Art. XIII.—*The Cainozoic Volcanic Rocks of the Gisborne District, Victoria.*

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[Read 14th September, 1939; issued separately 1st July, 1940.]

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Introduction.

The volcanic rocks which cap much of the Gisborne Highlands (fig. 1) belong to the Cainozoic Newer Volcanic Series, and range in type from limburgite to acid-trachyandesite. The points of eruption from which the lavas issued stand up as prominent hills, of which Mt. Gisborne (2,105′) and Mt. Bullengarook (2,207′) are the two highest. The greatest variety of rock types lies within the area bounded on the north by the Melbourne-Bendigo railway line, on the west by Goodman's Creek, on the south by the Coimadai-Toolern Vale road, and on the east by the Black Hills road. This area has been mapped in detail (fig. 2), mainly by Mr. W. Crawford, of Gisborne. The laboratory study and chemical analyses were made by Dr. Edwards at the Geology Department, University of Melbourne, by the kind permission of Professor Skeats.

General Geology.

The Volcanic Hills.

The eroded volcanic hills of the Gisborne Highlands appear at their most striking when viewed across "The Gap" from Schlossberg Hill, on the north side of Mt. Alexander Road (Calder Highway) about two and a half miles north-west of Digger's Rest township. Similar volcanic hills, Mt. Kororoit and

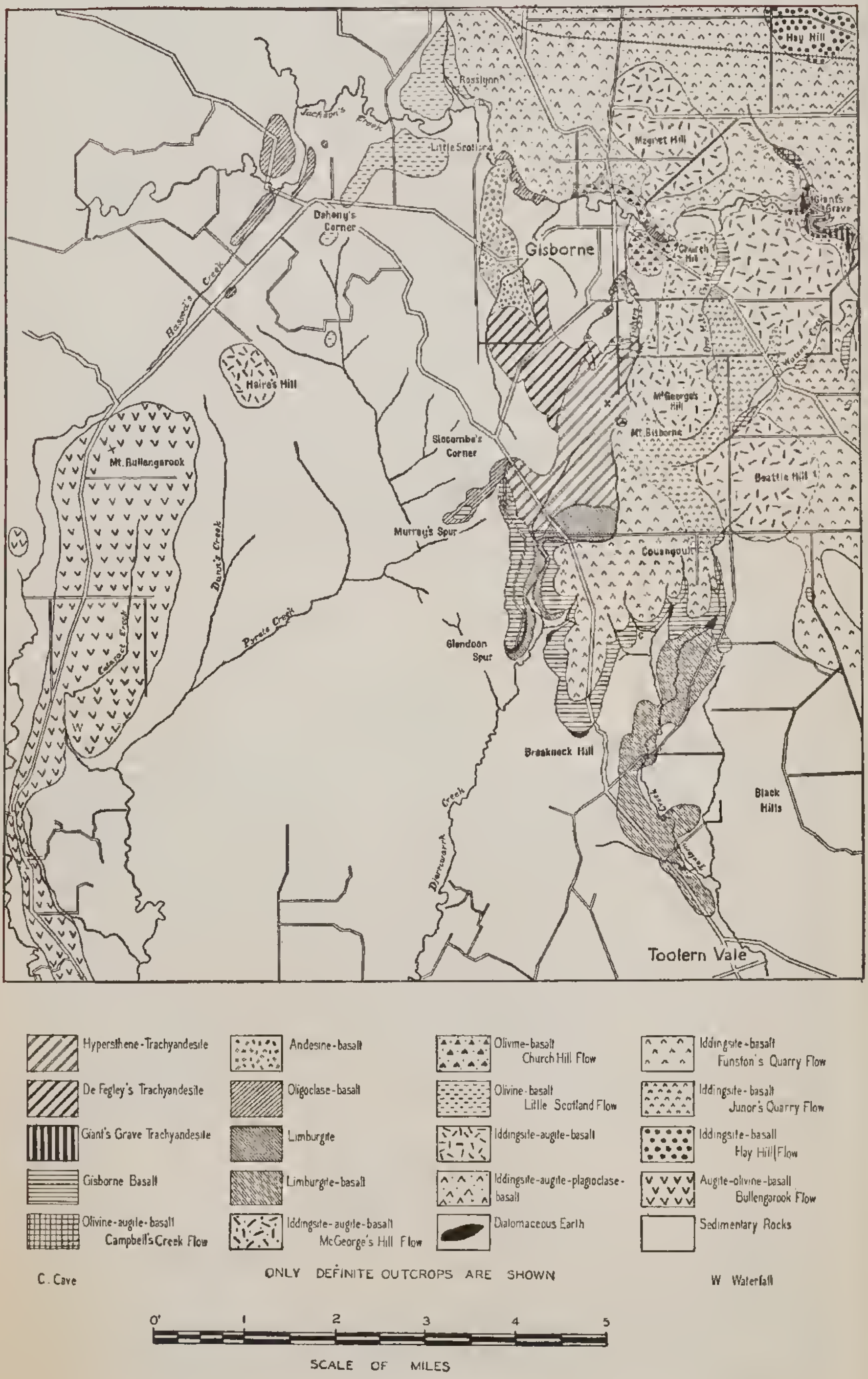

Fig. 2.—Geological Map of the Gisborne District, showing the distribution of the Newer Volcanic rocks.

Sheoak Hill, stand up to the south-west of this vantage point, on the northern margin of the low-level basalt plains abutting the Gisborne Highlands.

Several of these hills, namely Red Rock, Mogg's Hill, Deverall's Hill, O'Brien's Hill, and Mt. Holden, present closely comparable profiles—a more or less flat top surrounded by rocky cliffs on all sides but one, where there is an easy slope down to the surrounding plain. The sides of this sloping tract are also marked by rocky walls in their upper parts. These profiles arise from the fact that erosion of the scoriaceous material of the original cone has exposed the central plug of the volcano and the sides of the lava flow which breached the cone (fig. 3). The lavas that issued from these vents were among the latest extrusions of the district, and gave rise to a generally similar type of porphyritic iddingsite-augite-labradorite-basalt.

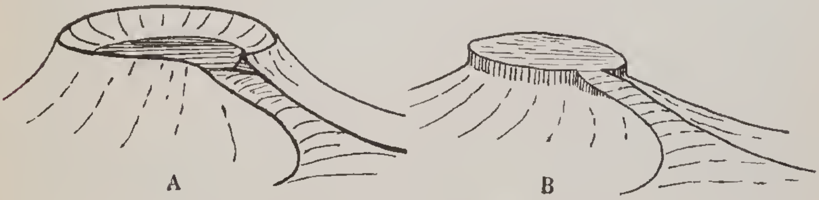

FIG. 3.—Illustrating the origin of the flat-topped volcanic hills in the Gisborne District. A. The breached volcanic cone. B. After erosion.

Mt. Gisborne.

Is the most westerly as well as the highest of the group of volcanic hills near Gisborne township and differs from the others both in appearance and structure. It consists of two peaks, the northerly one rising to 2,105 feet above sea level, and the southern one to just over 2,000 feet, with a saddle about 600 yards long connecting them. A third peak, McGeorge's Hill (1,900′) occurs on the north-eastern slope of the north peak, but really belongs to the group of flat-topped hills already described.

Mt. Gisborne is built up of a series of lava flows ranging in composition from limburgite to acid trachyandesite, with olivine-basalts predominating, and is the most complex Tertiary volcanic hill yet known in Victoria. It also appears to be the earliest centre of eruption in the Gisborne district, since its later flows are closely comparable with the flows from the adjacent cones. The volcanic activity appears to have commenced with the extrusion of flows of oligoclase-basalt, andesine-basalt, and limburgite. The andesine-basalt issued from near the northern flank of the present mount; the oligoclase-basalt flowed out to the west, filling a valley now represented by Murray's Spur; and the limburgite flowed southwards into a valley now represented by Glendon Spur. The vents from which these flows issued are hidden beneath later lava flows, and there is no evidence as to their order of extrusion. An extensive flow of limburgite-basalt occurred in the valley of the pre-basaltic Toolern Creek, and flowed down that valley towards Toolern Vale. The vent of this flow appears to have built up to a sufficient height to effectively dam the valley, and prevent any later extrusions from flowing down it. At about this time, also, the olivine-basalt of Church Hill, to the north of Mt. Gisborne, was extruded (probably from a vent near Magnet Hill, judging from its surface slope).

A period of quiescence followed these eruptions. Extensive deposits of impure diatomaceous earth, suggestive of temporary lake conditions, overlie the limburgite and limburgite-basalt flows (5).

The next extrusions are mostly characterized by the presence in varying amounts of partially resorbed hypersthene, labradorite, and anorthoclase. The most extensive are flows of olivine-basalt (the Gisborne Type). These directly overlie the diatomaceous earths, the oligoclase-basalt, limburgite, and limburgite-basalt, on the western and southern flanks of the mountain, and extend as far south as the higher Ordovician ground of the Breakneck and the Black Hills. On the east and north-east it is exposed beneath later basalts in several " windows " in creek beds, and along One Mile Creek in the vicinity of its junction with Jackson's Creek.

The Gisborne basalt was followed by the extrusion of a sheet of iddingsite-basalt (the Funston's Quarry flow), which extended as far south as the Ordovician hills, and also appears in the bed of Fisher's Creek, south of the township of Gisborne, and on the road leading from Gisborne to Mt. Gisborne, north-west of Section VII.

At least three flows of trachyandesite developed at this time. A glassy, basic trachyandesite (De Fegley's Flow) issued to the north-west, partially covering the earlier andesine-basalt flow down the pre-basaltic Carnegie's Creek. This in turn was partly covered by an acid, grey trachyandesite which also flowed out to the south-west, covering limburgite, Gisborne-basalt, and oligoclase-basalt, and to the north-east. Its full exent in this direction is hidden by later flows, but it is revealed in a " window " in One Mile Creek beneath the flow from McGeorge's Hill. A third trachyandesite, which outcrops as the third lowest of the four flows exposed in Jackson's Creek in the vicinity of the Giant's Grave, also probably came from Mt. Gisborne. Xenoliths in the trachyandesite suggest that a flow of hypersthene-basalt, now completely hidden, also occurred during this stage.

These were followed by an extrusion of iddingsite-augite-basalt from a new vent, McGeorge's Hill, on the north-eastern flank of the north peak of Mt. Gisborne. This stage seems to have coincided with a period of general activity throughout the district, when the various volcanic cones mentioned were formed. A generally similar type of lava issued from them all. Then a final extrusion from near the south peak gave rise to the Junor's Quarry flow of iddingsite-basalt (Ballan Type) on the eastern side of the mountain. This forked, going partly to the south-east and partly to the north-east, between and covering the porphyritic flows from McGeorge's Hill and Beattie Hill, as far as the Mt. Alexander Road.

Magnet Hill.

North of Gisborne and east of New Gisborne, is an oval-shaped hill of rather glassy porphyritic iddingsite-augite-basalt, more or less comparable with the McGeorge's Hill flow. It is probable that several flows issued from this vicinity. Only so can one explain the occurrence of an area of oligoclase-basalt to the south of Magnet Hill, in Jackson's Creek, and the olivine-basalt (Church Hill flow) which overlies this oligoclase-basalt. Iddingsite-basalt, which overlies the Church Hill flow and underlies the Magnet Hill porphyritic flow, may also have come from this source.

Hay Hill.

In the north-east corner of the area, is a small hill of fine-grained andesitic-basalt, overlying the widespread porphyritic type of the plain. It is similar to the latest (Junor's Quarry flow) flow from Mt. Gisborne.

Haire's Hill (Little Bullengarook).

West of Gisborne and close to the north-eastern flank of Mt. Bullengarook is Haire's Hill, a dome-shaped hill of porphyritic iddingsite-basalt which is more or less isolated, although a flow appears to have issued from it to the north-west.

Mt. Bullengarook (2,207′).

Immediately to the west of Haire's Hill provides a striking contrast. It consists of a pedestal of Ordovician sediments rising to at least 1,900 feet above sea level (5), capped by about 300 feet of basalts. The earliest flow appears to have been an oligoclase-basalt which flowed to the north, along what was presumably a continuation of the pre-basaltic Bullengarook River. This early flow has undergone a certain amount of erosion, and its outcrop is not everywhere continuous. Spoil from a well shaft on the northern flank of the hill indicates that this early flow is overlain by a porphyritic iddingsite-basalt similar to that of Hair's Hill. Overlying this there is a very considerable flow of porphyritic augite-olivine-basalt which flowed out to the south, filling the valley of the pre-basaltic Bullengarook River for a distance of twelve and a half miles. It is to this lava flow that Mt. Bullengarook owes its distinctive profile. A contour plan of this flow has been given by Charles Fenner (11, p. 260). In its widest part the flow is about a mile and a half across, but about four and a half miles downstream it narrows to almost nothing, and then widens again. There appears to be a distinct descent in level at this point, suggestive of a slight downwards movement of the block to the south. The basalt is similar on both sides of this point. Goodman's Creek and the Pyrete Creek (Dunns Creek at the northern end) have formed deep lateral streams on either side of this flow; while in the upper portions it has been deeply dissected by Cataract Creek, which starts as a slight depression on the surface of the lava, and quickly deepens into a gorge, with a waterfall where it spills over on to the Ordovician bedrock.

Lava Fields.

The form of the lava fields in the western part of the Gisborne Higlands is in striking contrast to those in the eastern part. The long narrow flow running south from Mt. Bullengarook is an excellent example of Keble's conception (14) of a "confined lava field," i.e. one in which the lava flow failed to completely fill the valley into which it flowed. The drainage flowing down such a valley is still retained between the original interfluves, but tends to reconstitute itself as a pair of lateral streams on either side of the lava field, which becomes elevated to the position of a ridge as erosion proceeds.

The lava field extending eastwards from Gisborne, on the other hand, is an example of an "extensive lava field." The earlier flows were confined within the pre-basaltic valleys, as in the western area, but repeated extrusions gave rise to such a volume of lava that the pre-basaltic topography was completely buried, except for the summits of a high ridge of Ordovician sediments trending north-east from Mt. Tophet towards Clarkefield, and the high ground to the west of Gisborne. The drainage was completely deranged, and developed as a new, sinuous stream (Jackson's Creek) consequent on the gradient of the lava plain. This stream has cut down below the surface of the plain, sometimes to the underlying bedrock, and has incised its sinuous course in the process giving rise to in-grown meanders. Where it crosses the infilled pre-basaltic valleys, as at the Giant's Grave, the extra thickness of lava flows has acted as a bar, causing the development of a narrow gorge. Where it has reached the softer bedrock the valley has widened as a result of undercutting, and flats have formed in which the stream has cut meanders.

The Giant's Grave.

This is a cut-off spur of one of the in-grown meanders. A pre-basaltic valley trending north-east existed at this point, and was infilled by a series of lava flows, of which four are exposed in section. The presence of soft or weathered rock at the base of the third flow (down) has enabled the stream to undercut the rock above this layer, until finally it breached the lava at this point, and broke through into its valley on the other arm of the in-grown meander. With further grading of its bed the stream has abandoned the meander, and has worn down the cut-off spur until it looks like an enormous burial mound set in a walled amphitheatre.

Waterfalls.

The gorge tract continues for some distance upstream to a waterfall, which has resulted from undercutting at the junction of the second and third lava flows of this series. Another waterfall occurs on Cataract Creek (Bullengarook flow) where the stream which has its origin on the surface of the small lava plain south of Mt. Bullengarook falls over the edge of the basalt on to the Ordovician sediments. Undercutting has produced a considerable waterfall at this point, and a narrow, gorge-like valley extends for some distance upstream.

AGE OF THE LAVA FLOWS.

Although the lava flows of the Gisborne district have a quite youthful appearance, the amount of erosion which they have undergone is sufficient to show that they are not of Recent age. They overlie the Bullengarook gravels (5), and were extruded after the differential uplift which raised the Gisborne Highlands above the plain to the south. There is no indication of any prolonged break between the lava flows at any stage; and since the later members appear to be contemporaneous with the basalts that cover these plains, and which are regarded as of Pleistocene age (4, p. 257), they are all probably of this age.

Petrology.

The volcanic rocks of the Gisborne district fall into two main groups:—(1) those which appear to be typical differentiates of an olivine-basalt magma, and (2) those which appear to be "abnormal" differentiates, namely the hypersthene-trachyandesites, and hypersthene-bearing basalts. For convenience the "abnormal" types are grouped together in the following petrological descriptions. The nomenclature used is the same as adopted in earlier papers (8, p. 256).

A. ABNORMAL DIFFERENTIATES.

TRACHYANDESITES.

Three flows of trachyandesite have been discovered in the Gisborne district.

Hypersthene-trachyandesite.

This rock outcrops on the north-western and south-western flanks of Mt. Gisborne, overlying the de Fegley's trachyandesite, Gisborne basalt, limburgite, and iddingsite-basalt (Funston's Quarry flow). It also outcrops in the bed of One Mile Creek, where it is overlain by the iddingsite-basalt, from McGeorge's Hill. It consists of phenocrysts of sanidine, anorthoclase and plagioclase felspars, and of hypersthene, augite, and occasionally olivine, set in a hyalopiltic to pilotaxitic groundmass. Rounded xenocrysts of quartz are present in every section. The sanidine phenocrysts are simply twinned or untwinned, and rounded. Their margins are generally vermiculate, owing to reaction with the enclosing magma. Sometimes this process of resolution has progressed so far that only a "brain structure" of felspar remains. Occasionally this corroded felspar shows closely-spaced but very faint lamellar twinning, suggesting that it is anorthoclase. The plagioclase, which shows strong lamellar twinning and sometimes zoning, is also corroded and frequently more or less vermiculate. The maximum extinction angle obtained in the symmetrical zone was 32°, corresponding to a composition of about Ab_{40}. These felspar phenocrysts, especially the plagioclase, tend to gather into clots, in company with crystals of hypershene and sometimes aguite. Some of the clots attain to 2 and 3 cm. in diameter, and resemble norites. They represent the preliminary stage in the formation of the norite xenoliths described below.

The hypersthene is distinctly pleochroic with X = pinkish to yellowish, Y = colourless or pale green, Z = green. It has a (—) 2V between 60° and 90°, so that it probably contains 20 to 30 per cent. of the $FeSiO_3$ molecule (En_{70}). The larger hypersthene crystals are somewhat corroded and even vermiculate, though never so much as the felspars. Small lath-like crystals of hypersthene occur in the groundmass, and are generally edged with a monoclinic pyroxene showing an extinction angle of about 40°. Occasionally the hypersthene crystals occur in small clots, free from felspar. A monoclinic pyroxene with a large extinction angle and (+) 2V greater than 45° also occurs as phenocrysts. It is presumably an augite and is not vermiculate. The pyroxene fringing the laths of hypersthene in the groundmass may be of the same composition.

Every section contains one or two rounded grains of quartz. These appear to be xenocrysts derived from assimilated sedimentary rock. They do not show any semblance of the forms usually exhibited by quartz phenocrysts in rhyolites or similar rocks. Moreover, microphenocrysts of olivine with iddingsite are occasionally present. In weathered specimens this olivine is more or less altered to serpentine. Large apatite crystals (1 mm. x 0.2 mm.) enclosing fibrous inclusions parallel to the prism axis also make an occasional appearance. The fibrous inclusions are pleochroic from brown to black. The groundmass consists of microlites or small laths of oligoclase (Ab_{75}), incipient pyroxene crystals, and dark glass.

As the analysis (Table I., No. 1) indicates, this rock is an acid trachyandesite, which closely resembles the trachyandesite flows of the Coliban district (8, p. 258) both in chemical and mineralogical composition.

de Fegley's Trachyandesite.

This is a dense, almost glassy, black rock, studded with phenocrysts of felspar that may be as large as 5 mm. across, but are generally smaller. It forms a flow on the north-western flank of Mt. Gisborne, overlying the andesine-basalt that outcrops near Bruecdale, and overlain by the trachyandesite just described. In hand specimen it somewhat resembles the black trachyandesite glass of the Coliban district (8, p. 258). In thin section it is seen to consist of phenocrysts of hypersthene, augite, partially resorbed plagioclase, and occasionally sanidine, in a hyalopilitic groundmass of oligoclase microlites (Ab_{80}), granules of pyroxene and abundant glass. Most of the glass is black and opaque under low magnification, but under high magnification resolves into innumerable globules of iron ore in a colourless base. Patches of a green, glassy material which turns yellow on weathering are also present.

The hypersthene phenocrysts are faintly pleochroic from pink to green, with (—) 2V between 60° and 90° (En_{70}), and are often partially resorbed, though some retain their idiomorphic outline. They enclose crystals of apatite and sometimes enclose granules or aggregated granules of augite. There is a marked tendency for the crystals to gather into glomeroporphyritic clots. The augite has (+) 2V greater than 45°, and although sometimes embayed, never shows the vermiculate structure so common in the felspar and hypersthene phenocrysts. The smaller plagioclase phenocrysts are rounded or lens-shaped, but the larger crystals and the sanidine phenocrysts (and anorthoclase?) show "brain structure" resorbtion to a marked degree. Xenocrysts of quartz are numerous. They are rounded and often appear to have suffered slight fusion at the edges. They never possess any suggestion of crystal outline, but are generally ovoid in shape and, like those in the acid trachyandesite, are probably derived from sediments.

A chemical analysis of this rock is shown in Table I., No. 2. It reveals it as a distinctly more basic variety of trachyandesite than the adjacent flow.

Giant's Grave Trachyandesite.

A further flow of trachyandesite, closely comparable in chemical composition (Table I., No. 3) to the de Fegley's flow, is exposed in Jackson's Creek in the gorge above and below the Giant's Grave, where it forms the third flow down from the surface. It extends from the waterfall above the Grave as far downstream as Watson's Creek, and outcrops in the bed of that creek, and also in the bed of Campbell's Creek for a short distanct upstream from its mouth. These exposures and a further one in the bed of a small creek (MacGregor's Creek) at the first bend downstream from the Giant's Grave, suggest that the bottom of the flow slopes to the north-east, in which case the lava flow came from the direction of Mount Gisborne. It overlies a flow of the Church Hill type of olivine-basalt, and is overlain by iddingsite-basalt, and iddingsite-augite-labradorite-basalt.

In microtexture also it resembles the de Fegley's flow. In the upper and lower parts of the flow the groundmass is largely glass which is practically opaque from the presence of iron-ore dust, and encloses a few highly vermiculate phenocrysts of labradorite and anorthoclase, together with an occasional crystal of aguite. In the central parts of the flow the groundmass is more crystalline, and consists of microlites of oligoclase, granules of iron ore, and greenish glass. Small microphenocrysts of pleochroic hypersthene are numerous, and occasionally have aggregated into clots along with stumpy columnar crystals of labradorite. Large phenocrysts of vermiculate labradorite and anorthoclase are not as numerous as in the chilled margins.

HYPERSTHENE-BASALT.

In the acid trachyandesite there occur numerous xenoliths, 2 to 3 cm. in diameter, of a grey, minutely vesicular rock, showing numerous growths about 1 cm. in diameter of radiating crystals suggestive of spherulitic growths. Thin sections revealed that these xenoliths consist of a hypersthene-basalt. Subsequently an ovoid xenolith of the same material, measuring 15 cm. x 10 cm. x 6 cm., was found and broken out of the trachyandesite. Further sections and an analysis were made of this rock, which is unique among Victorian basalts. Its close relation to the trachyandesites cannot be doubted.

It contains occasional phenocrysts of hypersthene and olivine The hypersthene shows distinct pleochroism from pink to green, and has (—) 2V between 60° and 90°, so that its composition may be taken as about (En_{70}). Occasionally it occurs in clusters of several crystals. The olivine phenocrysts occur only sporadically. They are corroded and rimmed with iddingsite. The bulk of the rock is a finely vesicular intergrowth of plagioclase and lath-like prisms of colourless hypersthene (bronzite ?) which are edged with a later pyroxene that has an extinction angle of 40°, measured from the extinction position of the hypersthene, and a distinctly higher hirefringence. The size of the hypersthene core in these laths is variable. Sometimes it forms only a needle inside the augite, at other times it forms the bulk of the crystal. These laths are identical, except that they are larger, with the hypersthene laths in the groundmass of the acid trachyandesite. The plagioclase occurs as short, stumpy laths and as allotriomorphic plates intersertal to the pyroxene laths. It has a composition about Ab_{35}. Iron ore occurs as numerous rods in this base, often moulded on the laths of pyroxene; and as granules intergrown with the marginal augite, though never with the hypersthene cores.

The close affinity of this rock to the trachyandesites is brought out by the analysis (Table I., No. 4), which also reveals the relatively high proporition of ferromagnesians to felspars in the rock.

NORITE XENOLITHS.

Reference was made in an earlier paper (8, p. 294) to the occurrence of norite xenoliths both at de Fegley's quarry, Gisborne, and elsewhere. During the present study, further xenoliths of this nature have been found both in the de Fegley's trachyandesites and in the grey trachyandesite. These consist of prisms of hypersthene (about En_{70}) intergrown with laths and allotriomorphic plates of labradorite (about Ab_{35}), sometimes with accompanying augite. They are clearly derived from the aggregation of the hypersthene and plagioclase phenocrysts in the trachyandesites, and every stage in their growth can be observed.

Recently the Director of the Geological Survey (Mr. W. Baragwanath) discovered a block of such xenolithic norite, about 20 cm. x 20 cm. x 15 cm., on the dump from a shaft sunk on the Campaspe Deep Lead, near Kyneton. A selvedge of the enclosing rock still adhered to part of the block, and a thin section showed it to be the less acid of the two trachyandesites which occur in that district (8, p. 258), so that this norite block is presumably of the same origin as the smaller xenoliths found at Gisborne. This rock consisted of coarse allotriomorphic crystals of labradorite (Ab_{30}) and interlocking crystals of strongly pleochroic hypersthene (about En_{70}) and faintly violet augite, together with iron ores, and occasional large apatite crystals with black fibrous inclusions. An analysis of this rock was made (Table I., No. 5) as more or less representative of these cognate xenoliths, and, as will be seen, it differs considerably in chemical composition from any other Newer Volcanic rock on record in its high CaO content and low alkalies. In mineral and chemical composition it compares somewhat with certain highly porphyritic Japanese basalts (21).

GISBORNE BASALT.

This distinct variety of basalt occurs to the south-west, south, east, and north-east of Mt. Gisborne, and thin sections in the University collection (Nos. 3547, 3558) indicate that a similar rock occurs north-east of the area near Riddell. At Murray's Spur the Gisborne basalt overlies oligoclase-basalt; at Glendoon Spur and south of Mt. Gisborne it overlies limburgite and limburgite-basalt, and at the mouth of One Mile Creek it overlies olivine-basalts of the Church Hill type. It is overlain in its turn by the acid trachyandesite on the south-west of Mt. Gisborne, and by a variety of iddingsite-basalt flows. The Gisborne basalt was almost certainly extruded as several flows, which have minor differences but a strong general resemblance.

In hand specimen it is a dark greenish-grey rock, showing phenocrysts of felspar up to 5 mm. in diameter, with fewer and smaller phenocrysts of pyroxene and olivine. The phenocrysts consist of anorthoclase and labradorite, hypersthene and augite, and olivine. The felspars are the dominant phenocrysts, and occur in crystals which are characteristically vermiculate from resolution. The proportions of olivine and pyroxene, on the other hand, are variable. When the one is abundant, the other is generally scarce.

Anorthoclase occurs as only occasional, large and generally composite phenocrysts, and is always highly vermiculate. Sometimes resolution has gone so far that only a "brain structure" of the original crystal remains. The dominant felspar is a labradorite (Ab_{40}), which is usually less vermiculate than the anorthoclase. In both cases the marginal zone generally has a composition similar to that of the groundmass felspar, so that it forms a clear margin about a vermiculate core. The more lath-like of the labradorite phenocrysts sometimes show fracturing from differential movement.

The hypersthene, like the anorthoclase, has a variable distribution, being much more abundant in some thin sections than others. It is particularly prominent in specimens from the south-west of Mt. Gisborne. It is usually pleochroic in weak tints of green and pink, with (—) 2V between 60° and 90°, indicating a composition about (En_{70}). It is invariably rimmed with augite. The width of such rims varies from a mere line to as much as the width of the enclosed hypersthene, and frequently consists of an aggregate of small granules and prisms of augite accompanied by iron ore. The dominant pyroxene is an augite (2V greater than 45°) which tends to be idiomorphic, and sometimes has a marginal zone not cleared of iron ore inclusions. It is colourless to brownish, and shows a tendency to segregate into clots.

The olivine is always corroded, and is sometimes partly altered to serpentine, but never to iddingsite. In the sections in which they are scarce, the olivine crystals are sometimes rimmed with granular pyroxene, after the manner of the hypersthene crystals. Where they are numerous, however, such rims are absent. Occasionally crystals of corroded olivine may be completely enclosed within crystals of augite, so that there can be no doubt that the augite began to crystallize considerably later than the other phenocrysts. Rarely one also observes rounded xenocrysts of quartz fringed with small, more or less radially arranged prisms of augite; and in one section a large crystal of apatite, with fibrous inclusions, pleochroic from brown to black, was present.

The groundmass, which consist of plagioclase laths, augite granules, grains of iron ore, apatite needles, and a variable amount of green glass, frequently has a distinctive orthophyric appearance. This derives from the tendency for the labradorite laths (Ab_{50}) to occur as short, stumpy prisms (0.2 to 0.4 mm. x 0.1 mm) which abut against one another without any parallel arrangement, while the much smaller pyroxene and iron ore granules (0.1 x 0.1 mm.) are relegated with the green glass to the interstices. In those specimens in which the felspar laths are not so large in respect to the other constituents of the groundmass, this distinctive appearance is lacking.

The analysis of a typical specimen (Table I., No. 6) shows that despite the obvious mineralogical affinities with the trachyandesites, this rock is not greatly different in composition from the other varieties of basalt in the area. The higher CaO content, reflecting the numerous labradorite phenocrysts, in conjunction with the relatively high SiO_2 and the low Al_2O_3 and MgO, gives the analysis considerable resemblance to that of a tholeiitic-basalt, a point which is of some significance, as will be indicated later.

Olivine-augite-hypersthene-basalt.

This variety is known only as an inlier exposed in the bed of Campbell's Creek, in the north-east of the area mapped. It is dark, greenish rock, showing phenocrysts of felspar, olivine, and augite. The felspar phenocrysts consist of labradorite and anorthoclase. The labradorite (Ab_{45}) crystals are all columnar in shape, and are generally rounded at the corners, sometimes to the extent of being lens-shaped. Sometimes they have been corroded so as to form re-entrants along their length. They are accompanied by less numerous but extremely vermiculate crystals of anorthoclase.

The pyroxene phenocrysts all appear similar in ordinary light, being brownish with a tinge of violet. Generally they consist of a core of corroded pyroxene, with a narrow fringe of slightly more violet colour, which is charged with minute particles of iron ore, like the pyroxene phenocrysts in the main flow from Mt. Bullengarook. All show extinction angles of 25°–30°. When their optic axial angles were observed, however, some appeared to have 2V about 60°, while occasional crystals had a lower 2V (about 45°). A slide of this rock was kindly examined for me by Mr. Paterson of Otago University, who measured the optic angles on a Universal Stage. He found that in the main they had 2V ranging from 53°–55°. One crystal, however, showed (—) 2V = 70 ± 5°, indicating hypersthene, while another showed a (+) 2V = 40°, indicating a pigeonite. He also noted that the 2V value was higher in the central part of one augite than on the margin, the range being from 2V = 55° to 2V = 47°. He also attempted to make measurements on the fine-grained pyroxenes of the groundmass. Four measurements were obtained (2V = 81°–86°), which suggest that some hypersthene (bronzite) occurs among the groundmass pyroxene, in addition to diopsidic augite.

TABLE I.

——	1.	2.	3.	4.	5.	6.
SiO_2	60·94	56·73	56·90	48·68	49·50	48·15
Al_2O_3	14·46	15·24	15·03	15·32	16·09	13·80
Fe_2O_3	1·23	2·80	2·98	6·71	3·92	1·77
FeO	5·29	6·11	5·90	7·36	6·19	9·66
MgO	2·49	3·91	3·29	6·88	7·11	6·93
CaO	3·65	6·53	6·45	5·99	13·30	10·10
Na_2O	4·95	3·39	3·00	1·44	1·47	2·91
K_2O	3·96	2·97	2·79	1·04	0·29	1·29
H_2O + ...	0·78	0·20	0·32	1·10	0·10	0·71
H_2O −	1·45	1·48	1·21	2·90	0·21	1·90
CO_2	tr.	nil	nil	nil	nil	0·05
TiO_2	0·45	0·75	1·60	1·87	1·95	2·00
P_2O_5	0·02	0·32	0·02	0·05	0·02	0·15
MnO	0·06	0·21	0·07	0·17	0·14	0·06
TOTAL ..	99·73	100·64	99·56	99·51	100·27	99·48

1. Hypersthene-trachyandesite, Allot. xi., Parish of Gisborne.
2. Hypersthene-trachyandesite (De Fegley's flow), Allot. xvii., Parish of Gisborne.
3. Hypersthene-trachyandesite, third flow from surface, Giant's Grave, Jackson's Creek, Gisborne.
4. Hypersthene-basalt, xenolith in trachyandesite, Allot. xx., Parish of Gisborne.
5. Hypersthene-gabbro (norite), block of cognate xenolith in trachyandesite, spoil heap from mine shaft on the Campaspe Deep Lead, near Kyneton.
6. Hypersthene-augite-olivine-basalt (Gisborne type), bank opposite cave at Couangoult, Allot. xxxiii., Parish of Gisborne.

Analyst: A. B. Edwards.

Another surprising feature of this rock is that the plagioclase laths in the groundmass consist of oligoclase (Ab_{75}). It seems highly probable that this rock belongs to, or is associated with, the trachyandesite group. It underlies the iddingsite-basalts, and is not far distant from the Giant's Grave trachyandesite.

B. NORMAL DIFFERENTIATES.

OLIGOCLASE-BASALTS.

Oligoclase-basalt occurs as a flow extending northwards from Mt. Bullengarook, along Hassed's Creek to beyond its junction with the Slate Quarry Creek; in the bed of Jackson's Creek both upstream and downstream from the Calder Highway bridge at Gisborne, where it underlies the Church Hill olivine-basalt; and along Murray's Spur, south-west of Mt. Gisborne, where it underlies the Gisborne type of olivine-basalt.

In hand specimen the oligoclase-basalts are extremely fine-grained and sometimes fissile. Phenocrysts are practically absent, although olivine occurs as scattered microphenocrysts. The bulk of the rock is a fine plexus of plagioclase laths, augite prisms, iron ore and colourless glass. The plagioclase laths mostly show straight extinction, but some show angles up to 10° in the symmetrical zone, indicating that they have the composition of basic oligoclase (Ab_{75}). Flow structure is sometimes well marked, but is never as pronounced as in the typical oligoclase-basalts (macedonites) of the Macedon district. The rock in the bed of Jackson's Creek is particularly fine-grained. Calcite is sometimes present in amygdules of several coarse crystals, or intergrown with the felspar laths in ophitic fashion.

An analysis has been made of the rock from Murray's Spur, and is shown in Table II., No. 1. The high figure for CaO in this analysis is due to the abundant calcite in the rock (CO_2 2.11). The MgO is also high, and is reflected by the presence of olivine in the rock. This, in conjunction with the relatively basic nature of the plagioclase, has led to the rocks being classified among the more basic group of olivine-oligoclase-basalts (8, p. 272). With increase of olivine content and further basification of the plagioclase, this rock would grade readily into the type of olivine-basalt found between Dohoney's Corner and Little Scotland.

Attention may be drawn here to the peculiar rock forming the chilled margin (on the western side) of the limburgite-basalt flow in Toolern Creek. As will be seen from Table II., No. 9, the composition of this rock approximates in many respects to that of an oligoclase-basalt, combined with the features of a limburgite. In thin section it appears somewhat altered and carbonatized, as indicated by the high CO_2 content (3.02) of the analysis. Olivine occurs only in small amount in this chilled edge, although it is abundant in the adjacent unaltered limburgite-basalt (Table II., No. 7). Soda, on the other hand, is concentrated in the chilled margin.

ANDESINE-BASALT.

A flow of andesine-basalt, closely related to the oligoclase-basalts, forms a flow extending from beneath the de Fegley's trachyandesite, via Brucedale, to Little Scotland, and thence for a short distance down Jackson's Creek. It also outcrops in Fisher's Creek, at the edge of the trachyandesite.

This rock contains no olivine and only a sparse amount of pyroxene. It consists essentially of microphenocrysts of plagioclase (Ab_{50}) in the form of small sub-parallel laths and square cross-sections, together with an occasional microphenocryst of augite ((+) 2V greater than 45°) set in an extremely fine-grained base of plagioclase microlites (Ab_{70}), rods of iron ore, granular pyroxene, and abundant black glass. The felspar microlites and iron ore rods are arranged at random and do not show the fluxion structure that characterizes the felspar phenocrysts, indicating that the base was wholly glassy at the time of extrusion. In places the iron ore has aggregated and developed micro-ophitic intergrowths with the groundmass plagioclase. In some sections the intersertal glass is so crowded with iron ore granules as to appear opaque; but under high magnification it resolves into globules and trichytes of iron ore in a colourless (felspathic) glass. Calcite is prominently developed, as is indicated in the analysis (Table II., No. 2), filling vesicles and interstices. In one section rosettes of small pyroxene crystals associated with calcite have accumulated at the edge of a vesicle, the crystals growing radially into the vesicle. The augite is presumably of late formation, and of a composition similar to that in the groundmass. One crystal showed an acute bisectrix figure with (+) 2V greater than 45°, indicating a composition more or less similar to that of the microphenocrysts.

This rock is really intermediate between the andesine-basalts and the olivine-poor oligoclase-basalts, and has elsewhere been referred to the latter group (8, p. 270, Table III., No. 5). Further consideration of it suggests, however, that the Na_2O and K_2O contents are somewhat low for a typical oligoclase-basalt, and that the plagioclase is slightly too basic for the rock to be included in that group.

Olivine-basalts.

The varieties of basalt occuring under this heading bear considerable resemblance to the type described elsewhere as the Trentham type of olivine-basalt (8, p. 281), and although their chemical compositions (Table II., Nos. 3, 4) do not altogether conform, may be conveniently regarded as members of that group.

The Church Hill basalt.

This type occurs at Church Hill on the Calder Highway, at the eastern end of Gisborne township, overlying the oligoclase-basalt on the southern side of Jackson's Creek. It also outcrops along the northern bank beneath iddingsite-basalt; and it occurs in the bed of Jackson's Creek beneath the trachyandesite at the Giant's Grave.

It is a bluish-green rock in hand specimen, and somewhat altered. In thin section it is seen to consist of phenocrysts of a magnesian olivine and diopsidic-augite, sometimes aggregated into clots, set in a medium to fine-grained groundmass of labradorite laths, pyroxene prisms and granules, grains of iron ore, and abundant devitrified green glass. The olivine phenocrysts are partially resorbed, and are somewhat altered to green serpentine. The pyroxene crystals often appear to be in a state of arrested growth, with their ragged margins not yet cleared of numerous small grains of iron ore. The groundmass plagioclase is labradorite, with a maximum extinction angle in the symmetrical zone of about 30°, corresponding to a composition Ab_{45}. Occasionally laths attain the size of microphenocrysts; and sometimes the groundmass pyroxene forms irregular or lens-like patches in which it occurs in ophitic intergrowth with the groundmass plagioclase. The analysis of a typical specimen is given in Table II., No. 3.

Little Scotland Basalt.

A somewhat related flow of olivine-basalt extends from south of Dohoney's Corner to Little Scotland on the south side of Jackson's Creek, and similar rock outcrops on the north side of the Creek at Rosslyn, where it passes under the iddingsite-basalt. The olivine phenocrysts in this rock are quite fresh, and there is an absence of green glass from the base. Pyroxene occurs as occasional phenocrysts, but is restricted in the main to the groundmass, where it tends to occur as clusters of granules associated with grains of iron ore. Occasionally these clusters appear to have coalesced into microphenocrysts. The plagioclase laths of the groundmass appear somewhat less basic than those of the Church Hill basalt, and lie between basic andesine, Ab_{55}, and very acid labradorite, Ab_{50}. Calcite is present filling amygdules, and lining occasional vesicles. It also occurs in the groundmass, in ophitic intergrowths with the plagioclase laths.

The basalt at Rosslyn appears to be intermediate between this flow and the basic oligoclase-basalts. It has most of the features of the Little Scotland basalt, but is relatively free from olivine phenocrysts.

Augite-olivine-basalt.

One of the most distinctive basalts of the district is that forming the main southward flow from Mt. Bullengarook. This consists of numerous phenocrysts of augite, sometimes 1 cm. in length, with fewer crystals of olivine, in a groundmass of labradorite laths (Ab_{45}), augite prisms, iron ore, apatite needles, and felspathic glass. The augite phenocrysts are always rimmed with a narrow margin of granular augite, studded with minute grains or iron-ore. This granular augite appears to be coalescing or growing on to the phenocryst, and had not succeeded in clearing itself of iron ore at the time of extrusion. The same phenomena may be observed in other rocks of the district, both at the margins of the phenocrysts, and in the groundmasses, where the minute prisms of pyroxene seem first to cluster together and then coalesce into larger grains which progressively clear themselves centrally of the minute iron-ore grains that are associated with the prisms of groundmass augite.

The groundmass of the Bullengarook flow has a distinctive orthophyric appearance for several miles from the vent, because in this part of the flow the labradorite laths are much more strongly developed than the other minerals of the groundmass, being as much as five times the length of the pyroxene prisms. As a result, the augite prisms, iron-ore grains, and glass, form, together with plagioclase microlites, a dark base in which the coarser laths stand out. This feature becomes less pronounced as one follows the flow away from its source. The augite prisms and iron-ore granules grow in size, and tend to aggregate into micro-clots, while the felspathic glass crystallizes to an increasing extent. This combined with fluxion texture, detracts from the prominence of the earlier-formed laths of groundmass plagioclase.

A feature of one slide of very glassy rock from the western side of the vent is the presence of a number of minute flakes of biotite, strongly pleochroic from foxy red to pale straw. The biotite seems to have been the last mineral to form.

An analysis of this flow made from a specimen from the north wall of the vent reveals that it is practically identical in composition with the fresh limburgite-basalt of Toolern Creek, except for a slightly higher alumina content and lower titania (Table II., No. 4). Advantage was taken also of the coarseness of the pyroxene phenocrysts to separate sufficient for analysis. The analysis (Table III., No. 2) shows that they are fairly typical aluminous augites, closely comparable with the augite in the Mt. Koroit tuff, and the iddingsite-augite basalt overlying the Giant's Grave trachyandesite at Watson's Creek.

IDDINGSITE-BASALTS.

The more recent lava flows are all iddingsite-basalts, and belong to the widespread groups elsewhere designated as Malmsbury and Footscray basalts (8, p. 280). Three variations can be distinguished.

(1) *Iddingsite-basalts.*

These are finely vesicular, grey rocks, generally showing small phenocrysts of iddingsite in the hand specimen. They occur typically as the Junor's Quarry flow at Mt. Gisborne; at Hay Hill; as the second flow at the Giant's Grave; and as the Funston's Quarry flow, extending south from Mt. Gisborne. In this section they are found to consist of numerous, somewhat corroded phenocrysts of otherwise idiomorphic olivine (0.1–0.25 mm.) which have been altered marginally to iddingsite, in a fine-grained intergranular groundmass of plagioclase laths, pyroxene prisms, iron-ore grains, granules of iddingsite, and sometimes glass. Flow structure is often prominent, as in the Junor's Quarry flow. The felspar laths show extinction angles in the symmetrical zone ranging up to 30°, corresponding to Ab_{45}. The groundmass pyroxene prisms show extinction angles of 41°—43°, so that they are diopsidic. Very occasionally plagioclase and pyroxene occur as microphenocrysts.

The flow structure is less pronounced in the Funston's Quarry flow, in which the felspar laths tend to be thicker, and the pyroxene tends to occur as granules rather than as prisms. Analyses of the Hay Hill and Junor's Quarry flows are shown in Table II., Nos. 5 and 6 respectively.

(2) *Iddingsite-augite-basalts.*

In this variety both olivine and augite occur as phenocrysts. The olivine crystals range from 1.0 mm. down to 0.1 mm. in diameter. They tend to be idiomorphic, and show alteration to iddingsite. The smaller crystals are generally completely altered to iddingsite, while the larger ones have been replaced by iddingsite at the margin and along cracks. The iron ores are sometimes moulded upon the iddingsite rims.

The augite forms still coarser idiomorphic crystals, from 1 to 2 mm. in diameter, which are colourless to grey-violet. The rims are usually clear, but the central parts are often "spongy" with inclusions of iron ore and iddingsite granules. Occasionally they occur in clots in which the numerous individuals are much smaller than the single crystals. Very occasionally crystals are observed with a core that is pleochroic from greenish to yellowish, and with a low extinction angle. Such phenocrysts as showed an acute bisectrix figure had 2V greater than 45°, indicating that they were diopsidic; and a chemical analysis of a single extra-large crystal from the surface flow near Watson's Creek confirmed this (Table III., No. 3).

The groundmass consists of laths of labradorite (Ab_{40-45}) intergrown with rods of iron ore, granular pyroxene and iddingsite, representing a groundmass phase of olivine. A variable amount of glass occurs in the groundmass.

In some sections the felspar shows a tendency to be microporphyritic, indicating a gradation between this variety of iddingsite-basalt and group (3). Still more rarely a large crystal of enstatite is present, or a large vermiculate plagioclase.

This variety occurs at Mt. Bullengarook below the main flow, and at Haires Hill, Magnet Hill, and Beattie's Hill. The flow from McGeorge's Hill contains numerous plagioclase phenocrysts and is intermediate between this group and group (3) below.

(3) *Iddingsite-augite-plagioclase-basalt.*

This rock occurs as the surface flow at the Giant's Grave, where it is of wide extent, at Mt. Kororoit, to the south of the Gisborne Highlands, and at Red Rock and similar hills. It consists of numerous phenocrysts of iddingsitized olivine, augite, and labradorite in a fine-grained intergranular groundmass. The olivine crystals are idiomorphic, and range from crystals 1.5 to 2 mm. in length, down to small crystals in the groundmass. The iddingsite developed at a late stage, since it post-dates the shrinkage cracks in the larger olivine crystals, and is absent where the olivine is in contact with augite. The augite forms fewer but still frequent idiomorphic crystals ranging from 0.1 to 0.5 mm. in diameter. The central parts of these crystals are generally clear, but they are fringed with a narrow margin that has not cleared itself of iron oxide inclusions. The crystals show a large optic axial angle (2V greater than 45°), and is therefore diopsidic. Analysis of hand-picked pyroxene crystals from blocks of tuff associated with this type of rock at Mt. Kororoit (Table III., No. 1), shows this pyroxene to be a normal aluminous augite, similar to the augite phenocrysts in the iddingsite-augite-basalts, and the augite-olivine-basalt from Mt. Bullengarook.

The distinctive feature of this variety is the abundance of slightly rounded phenocrysts of labradorite (Ab_{40}) that occur in it. These are 1 to 1.5 mm. long and 0.2 to 0.3 mm. wide, with well developed lamellar twinning, and less frequently, zoning. They are generally rimmed with a narrow ragged margin of groundmass felspar. The groundmass is relatively fine-grained and intergranular. It is composed of plagioclase laths (Ab_{45-50}) and much smaller prisms of pyroxene (extinction angle 41°—43°), granules of iron ore and grains of iddingsite.

These three varieties of iddingsite-basalt appear to illustrate the manner in which the basaltic magma differentiated. In the one type olivine occurs alone as phenocrysts; in the next olivine and augite together form phenocrysts; while in the third olivine and augite are associated with basic labradorite, which is already beginning to re-dissolve. Presumably the plagioclase was the first of the three minerals to crystallize or begin to crystallize, and accumulated either by sinking or more probably by floating. Subsequently olivine began to crystallize and sink, giving rise to a graded MgO content within the magma; and was later joined by augite.

LIMBURGITES AND LIMBURGITE-BASALTS.

Limburgite and limburgite-basalts occur on the south-western side of Mt. Gisborne, in the valleys of the Djerriwarrh and the Toolern Creeks respectively, where they attain thicknesses of over 50 feet.

The limburgite consists of crystals of olivine, which are either fresh or only slightly iddingsitized, and have idiomorphic outlines, accompanied by smaller prisms of greenish augite with narrow rims of titanaugite set in a groundmass of similar but still smaller prisms of augite, octahedra of magnetite, and brown glass. In some sections the magnetite crystals are almost as large as the augite prisms; in others the augite tends to show stellate growth. It has a 2V greater than 45°, so that it is probably rich in lime. Occasional xenocrysts of quartz occur as rounded grains rimmed with minute columnar prisms of pyroxene. Under high magnification the brown glassy mesostasis is seen to consist of colourless glass crowded with trichytes of iron oxide and minute prisms of violet augite. In patches the colourless glass has crystallized as felspar.

TABLE II.

——	1.	2.	3.	4.	5.	6.	7.	8.	9.
SiO_2 ..	51·59	51·82	49·83	45·40	52·01	49·25	45·81	46·28	46·24
Al_2O_3 ..	14·52	15·15	13·76	14·23	13·50	13·87	12·45	13·63	12·83
Fe_2O_3 ..	2·15	1·78	4·77	6·77	6·25	6·78	9·20	5·08	5·15
FeO ..	8·59	8·69	7·77	7·41	4·82	6·29	2·86	8·90	6·35
MgO ..	4·11	3·62	5·76	8·06	8·48	7·24	8·83	8·38	3·63
CaO ..	7·49	7·97	7·05	9·05	7·81	8·46	10·00	9·38	10·48
Na_2O ..	3·45	3·03	2·93	2·68	2·74	2·95	2·86	2·75	4·41
K_2O ..	2·10	1·41	1·84	1·14	1·17	1·76	1·07	2·43	1·64
$H_2O +$	0·98	1·37	0·50	1·20	0·67	0·12	1·97	0·21	1·10
$H_2O -$	1·10	0·77	1·95	0·95	0·24	0·85	1·55	0·47	1·45
CO_2 ..	2·11	1·42	nil	0·10	nil	0·05	nil	nil	3·08
TiO_2 ..	1·35	2·10	1·87	1·25	2·20	2·01	2·80	2·31	1·70
P_2O_5 ..	0·81	0·31	0·78	1·25	0·39	0·08	0·69	0·28	1·32
MnO ..	0·16	0·16	0·29	0·17	0·07	0·27	0·21	0·23	0·23
Cl ..	0·04	0·03	..	..	tr.	..	0·04	..	0·07
S ..	0·04	nil	..	..	tr.	..	nil	..	nil
BaO ..	0·03	0·03	..	..	..	..	0·04	..	0·05
TOTALS	99·90	99·66	100·10	99·66	100·38*	99·98	100·38	100·31	99·73

* Li_2O nil, CoO, NiO 0·03.

1. Olivine-oligoclase-basalt, west end of Murray's Spur, west-south-west of Mt. Gisborne. Parish of Gisborne. (*Quart. Journ. Geol. Soc.*, xciv., p. 271, Table III., No. 8.) A. B. Edwards.
2. Andesine-basalt. north-east corner of Allot. 25, Parish of Gisborne. (*Quart. Journ. Geol. Soc.*, xciv., Table III., p. 270, No. 5.) A. B. Edwards.
3. Olivine-basalt, Church Hill, Allot. 2, Parish of Gisborne. A. B. Edwards.
4. Olivine-augite-basalt, north side of Mt. Bullengarook (main flow). A. B. Edwards.
5. Iddingsite-basalt, Hay Hill. (*Bull. Geol. Surv. Vic.*, No. 24, p. 35.) A. G. Hall.
6. Iddingsite-basalt, Junor's Quarry, Allot. 17, Parish of Gisborne. A. B. Edwards.
7. Limburgite-basalt, Toolern Creek, Sect. 19, Parish of Yangardook. (*Quart. Journ. Geol. Soc.*, xciv., p. 290, Table IX., No. 1.) A. B. Edwards.
8. Limburgite, Djerriwarrh Creek, Allot. 5, Parish of Gisborne. A. B. Edwards.
9. Marginal rock of limburgite-basalt flow, Toolern Creek, road from foot of the Breakneck, Parish of Yangardook. (*Quart. Journ. Geol. Soc.*, xciv., p. 270, Table III., No. 6.) A. B. Edwards.

The limburgite-basalt flow in Toolern Creek differs from the Djerriwarrh limburgite in two respects. A proportion of the glass has crystallized out as plagioclase laths or microlites of composition about Ab_{55}—Ab_{50}. In addition the idiomorphic crystals of olivine are completely altered to iddingsite. The otherwise close similarity of the two rocks is shown by a comparison of their chemical analyses (Table II., Nos. 7 and 8). A third specimen which was analysed, from near the extreme edge or base of the limburgite-basalt in Lower Toolern Creek, is an extremely difficult rock to classify. The olivine crystals in it, which were distinctly less numerous than in the central parts of the flow, are much altered, and a considerable amount of calcite is present. The base is more glassy, moreover, and corresponds to the true limburgite of Djerriwarrh Creek in the practical absence from it of felspar. On the other hand, the analysis (Table II., No. 9) of this chilled edge of the Toolern limburgite-basalt is in many respects comparable with that of an oligoclase-basalt, and would be so classified if no account was taken of its field occurrence.

Mineralogy.

PYROXENES.

Augites.

The common pyroxene in the Gisborne rocks, apart from the trachyandesites and closely allied types, appears to be a diopsidic augite. Approximate measurements of 2V were made whenever a crystal was found which showed an acute bisectrix figure; and these always gave values of 2V greater than (+) 45°, indicating diopsidic augite. In this the author follows Kuno's (17) use of the name pigeonite for monoclinic pyroxenes with (+) 2V less than 45°, and the name augite for those with (+) 2V greater than 45°. These measurements were confirmed for me by measurements of 2V of pyroxenes in the Campbell's Creek flow, made on a universal stage by Mr. O. D. Paterson of Otago University, New Zealand, through the kindness of Professor W. N. Benson. Mr. Paterson found that the augites showed (+) 2V of from 53° to 55°, with a tendency to be more pigeonitic at the margins than in the centre. One crystal had $2V = 55°$ in the centre and $2V = 47°$ near the margin. This would suggest that the groundmass pyroxene tends to be more pigeonitic than the phenocrysts, bearing out Barth's (2) observations.

The occurrence of large phenocrysts of pyroxene in several of the lava flows provided an opportunity for further check by determining their chemical composition. Clean samples for analysis were obtained from a block of tuff at Mt. Kororoit (south of the area mapped), from the Mt. Bullengarook (main flow), and from the iddingsite-basalt near Watson's Creek. The analyses (Table III., Nos. 1, 2, 3) show that all three are aluminous augites of generally similar composition.

It was not possible to make a direct comparison of the composition of the groundmass pyroxene in any of these rocks with those of the phenocrysts, owing to lack of means of achieving the necessary separation of the two pyroxenes. Recourse was made, therefore, to a specimen of olivine-oligoclase-basalt from Murray's Spur, thin sections of which appeared to contain very few phenocrysts of pyroxene. This rock was crushed to minus 100 mesh, and the ferromagnesians separated in bromoform in a hand centrifuge. The heavy fraction was re-centrifuged, dried, and the free iron oxides removed magnetically. It was then allowed to stand in cold concentrated hydrochloric acid for one month to dissolve the olivine associated with the pyroxene, after which it was washed, dried, and again centrifuged with bromoform to remove gelatinous silica produced by the breakdown of the olivine, and any remaining felspar. On examination under the microscope it appeared to be practically free from olivine or felspar. A considerable amount of iron ore remained, however, as minute inclusions in the pyroxene. As only a small quantity of material was left, it was analysed without further treatment.

TABLE III.

PYROXENES AND OLIVINE FROM GISBORNE DISTRICT.

——	1.	2.	3.	4.	5.
SiO_2	48·80	48·31	47·5	47·81	39·17
Al_2O_3	4·93	6·39	6·0	5·64	nil
Fe_2O_3	4·30	0·30	10·71	19·55	nil
FeO	8·37	8·28			9·88
MgO	14·57	14·15	14·3	10·85	49·48
CaO	17·60	18·19	19·5	13·16	nil
Na_2O	0·40	0·55	..	..	n.d.
K_2O	nil	0·25	..	..	n.d.
H_2O	0·15	0·30	..	..	1·00
TiO_2	1·20	2·37	0·5	3·40	nil
P_2O_5	tr.	tr.	nil	tr.	nil
MnO	0·17	1·13	1·5	0·07	0·41
TOTALS ..	100·49	99·46	100·0	100·48	99·94
CaO/MgO ..	1·208	1·285	1·294	1·213	

1. Pyroxene from tuff, Mt. Kororoit (similar pyroxene abundant as phenocrysts in lava flow).
2. Pyroxene phenocrysts, Mt. Bullengarook flow (Analysis No. 4, Table II.).
3. Pyroxene, large phenocryst (0·2 gm.) in basalt near Watson's Creek, Gisborne.
4. Contaminated groundmass pyroxene (0·3 gm.) from olivine-oligoclase-basalt, Murray's Spur, Gisborne.

Sample contained numerous micro-inclusions of iron ore, which accounts for the high FeO value. Only the CaO/MgO ratio can be compared with Nos. 1–3.

5. Olivine from iddingsite-basalt, Magnet Hill, Gisborne.

Analyst: A. B. Edwards.

TABLE IV.

FELSPARS FROM GISBORNE DISTRICT.

——	1.	2.
Na_2O	3·85	2·79
K_2O	7·36	0·48

1. Mixed felspars (sanidine, anorthoclase, and labradorite), from trachyandesite, Allot. xi., Parish of Gisborne.
2. Plagioclase from Mt. Kororoit tuff. Similar to phenocrysts in lava flow.

Analyst: A. B. Edwards.

The result is shown in Table III., No. 4, from which it will be seen that the ratio of CaO to MgO in this groundmass pyroxene is not greatly different from the CaO : MgO ratios of the analysed phenocrysts. The Al_2O_3 content is also comparable; but the iron and titania contents cannot be compared, owing to the contamination of the groundmass material with iron ores. It cannot be assumed, however, that these results disprove Mr. Paterson's observations as to the pigeonitic trend in the later pyroxenes, since in the rock selected it is possible that the augite which might have formed phenocrysts with slower cooling has entered into the composition of the groundmass pyroxene.

Hypersthenes.

The hypersthene, which is present in the trachyandesites and associated rocks, showed a (—) 2V greater than 60° and less than 90° in all the sections on which measurements could be made; and Mr. Paterson, in one measurement on a hypersthene crystal in the Campbell's Creek basalt, obtained a value (—) $2V = 70°$, corresponding to ($En_{70}Hy_{30}$). He also detected the presence of a more magnesian hypersthene in the groundmass of this basalt, four measurements showing (—) $2V = 81°—86°$, corresponding to a composition about ($En_{80}Hy_{20}$).

Pigeonite.

One phenocryst in the slide of Campbell's Creek basalt examined by Mr. Paterson gave a value of (+) $2V = 40°$, indicating that it is a pigeonite, the first to be recorded in the Newer Volcanic rocks.

OLIVINES.

Approximate measurements of the optic axial angles of a number of olivine crystals were made from sections cut normal to an optic axis. These gave the impression that the olivine was magnesia-rich, with not more than 10 per cent. of $FeSiO_3$. This is borne out by the analysis of hand-picked olivine from a small clot in the iddingsite-basalt of Magnet Hill (Table III., No. 4).

FELSPARS.

Partial analyses were made of a hand-picked specimen of porphyritic felspar from the acid trachyandesite of Mt. Gisborne, and of plagioclase crystals obtained from a block of tuff at Mt. Kororoit. The felspar from the trachyandesite proved to be composite, consisting of sanidine, possibly anorthoclase, and labradorite. This is clear from the composition as calculated from the partial analysis (Table IV., No. 1). Such a composition would fall in the middle of the immiscibility gap of Alling's (1) felspar diagram.

The plagioclase from Mt. Kororoit is a basic labradorite (Table IV., No. 2), and is presumably similar to the phenocrysts which occur in the Mt. Kororoit and related lava flows.

APATITE.

The occasional large crystals of apatite with pleochroic fibrous inclusions in the acid trachyandesite, the norite xenolith, and the Gisborne basalt are identical with those found in differentiated rock types at Macedon and elsewhere (8, p. 303). The frequent association of this peculiar type of apatite with basaltic hornblende that is breaking down into aegirine and iron ore has led the author to the opinion that such apatite is a characteristic by-product of this breakdown. It may be noted here that such an apatite was found recently in association with a much altered phenocryst (xenocryst ?) of hornblende in a slide of anorthoclase-trachyte from Macedon district.

Petrogenesis.

ORIGIN OF THE TRACHYANDESITES.

In an earlier paper (8, p. 314) it was tentatively suggested that the trachyandesites in the Coliban district might have originated through the assimilation of sediments by the basalt magma as it stoped its way upwards in a cupola-like chamber. The Gisborne trachyandesites strengthen this supposition. Their intimate association with the other rock types forming Mt. Gisborne demonstrates beyond doubt their derivation from an olivine-basalt magma. They appear, however, to have followed a different mode of differentiation to that taken by the more usual trachytic and oligoclase-basalt differentiates of the Victorian basalt magma. The trachytic differentiates appear to have developed through the early crystallization of olivine, augite, and plagioclase, accompanied by a tendency for anorthoclase and sanidine to crystallize and float up into the top of the magma chamber. The trachyandesites, on the other hand, have developed as a result of the crystallization of hypersthene (with some augite) and basic plagioclase. This tendency has been superposed upon the tendency for anorthoclase and sanidine to form. The fact that the hypersthene and plagioclase subsequently became unstable and commenced to re-dissolve in the magma, suggests that this superposed tendency was a passing one.

At this stage it is necessary to digress briefly into some general considerations. It is well known that two types of basaltic petrographic provinces exist, and that quite different processes of differentiation develop in each. Kennedy (15) has introduced the terms "olivine-basalt magma type" and "tholeiitic magma type" to describe the parent magmas of these two types of province. The igneous rocks of the Cainozoic Circum-Japan Sea province (20) and those of the islands of Japan (21) respectively, provide excellent examples of the suites derived from these respective magmas. When the CaO and MgO contents of the rocks of these (and similar) suites are plotted against their Al_2O_3 contents, as in fig. 4, the curves obtained show characteristic features and differences. As fig. 4 reveals, differentiation of the undersaturated, or olivine-basalts, results in the removal of CaO and MgO from the more acid differentiates (residual magma)

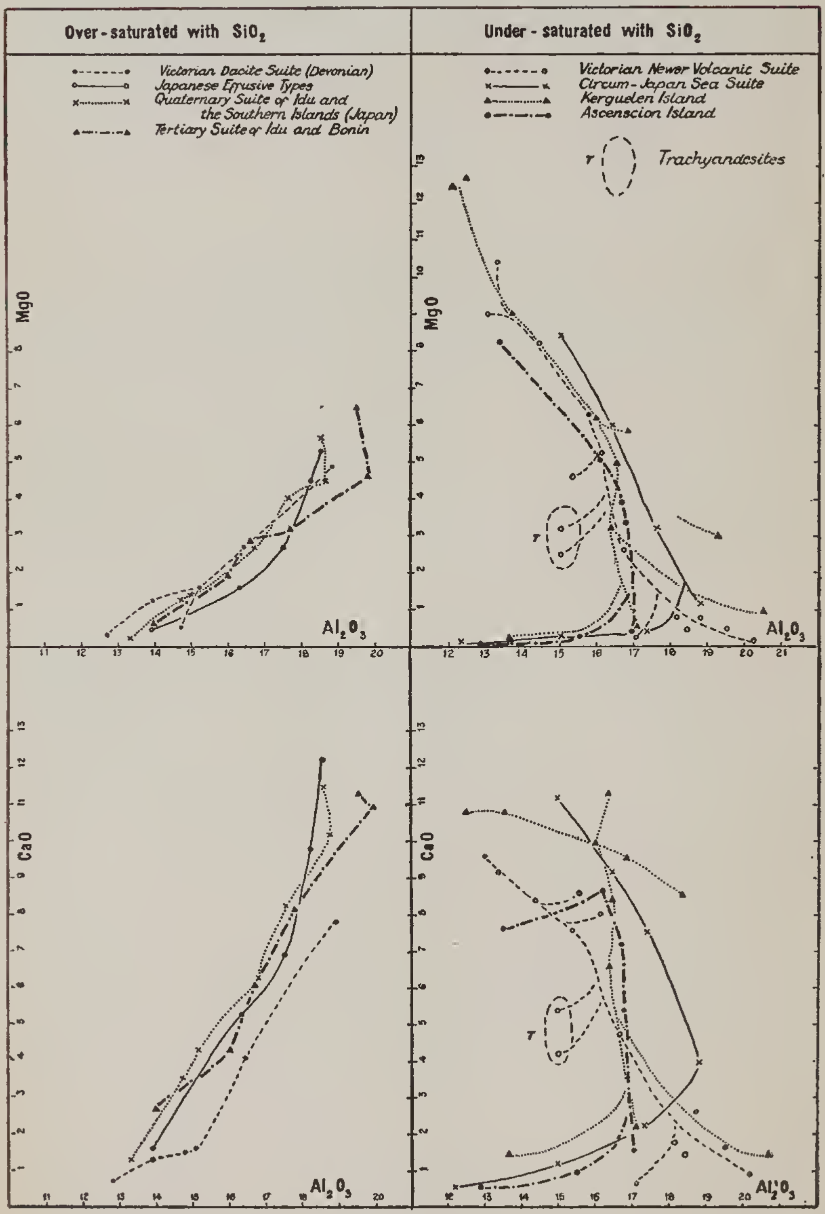

FIG. 4.—Variation diagrams to illustrate the contrasted differentiation of over-saturated and under-saturated basaltic magmas and the anomalous nature of the Victorian trachyandesites.

independently of Al_2O_3, which accumulates in the residuum. The differentiation of the saturated, or tholeiitic magma, on the other hand, leads to the simultaneous removal of CaO, MgO, and Al_2O_3, and yields an acid residuum relatively poor in Al_2O_3.

The olivine-basalt magma is undersaturated with SiO_2 from the outset, and contains abundant MgO. As a result olivine forms abundantly, and this tends to increase the SiO_2 content of the residual magma. Lime, on the other hand, begins to be precipitated partly as augite, a SiO_2-saturated mineral with a low Al_2O_3 content, and partly as basic plagioclase, which is rich in Al_2O_3 but poor in SiO_2. The olivine and augite tend to sink in the magma, whereas the tendency of the basic plagioclase is to float upwards. The trend, therefore, is for the increase of SiO_2 produced in the residual magma by the sinking of olivine to be balanced by the low SiO_2 content of the plagioclase that floats up into the residuum. At the same time only a small amount of Al_2O_3 is removed by either olivine or augite, while a considerable amount of it tends to be carried up into the residuum by the early-formed basic plagioclase. As a further outcome of this tendency, MgO is removed from the magma much more rapidly than CaO during the early stages of differentiation—a fact noted elsewhere (8, p. 311) in connexion with the olivine-basalts of Victoria.

The tholeiite magma, on the other hand, is saturated with respect to SiO_2 from the outset. The minerals which form early are found to be olivine (which forms in restricted amounts and soon re-dissolves), abundant hypersthene, with a lesser amount of augite, and abundant basic plagioclase. The residual magma is considerably more acid than that derived from the olivine-basalt magma, and presumably has a lower specific gravity, so that all these minerals tend to sink in it (at varying rates). The MgO is removed chiefly as hypersthene. The basic plagioclase, being the most Al_2O_3-rich of all common igneous rock-forming minerals, and at the same time the poorest in SiO_2 content of all the plagioclase series, leaves the magma depleted in Al_2O_3 and CaO, but relatively enriched in SiO_2; and some CaO and Al_2O_3 is removed by the augite.

The distinctive feature of the Gisborne (and Coliban) trachyandesites is that they have been derived by the temporary superposition of a " tholeiitic process of differentiation " upon a basalt magma which had previously been behaving as an olivine-basalt magma. In other words, the undersaturated olivine-basalt magma behaved temporarily as a saturated magma. A possible explanation of this anomaly is provided by Barth (3), who emphasizes the unlikelihood of there being just two types of primary basalt magma of well defined composition, and suggests that it is more probable that primary basalt magma, as a whole, is of a composition which varies locally between these two extremes of undersaturation and oversaturation with respect to SiO_2. So long as the primary magma is sufficiently undersaturated it will behave as an olivine-basalt magma, while so long as it is sufficiently oversaturated it will behave as a tholeiitic magma. If, however, a local primary magma lies in the more or less narrow range of composition between oversaturation and undersaturation, the manner of its differentiation will be highly susceptible to quite slight changes in the conditions affecting it, and may under some circumstances give rise to mixed end-products.

As has been indicated elsewhere (8, p. 313), the parent magma of the Cainozoic Newer Volcanic Series in Victoria appears to have approached this intermediate composition; for while it has behaved in the main as an olivine-basalt (fig. 4), the less differentiated rocks developed from it show some distinctly tholeiitic features and the trachyandesites reveal a tendency towards a tholeiitic line of differentiation (fig. 4). The suggestion is, therefore, that in certain localities the residuum of this differentiating magma became temporarily oversaturated with respect to SiO_2. This may have arisen under perfectly normal circumstances, such as those which give rise to small quantities of sanidine-rhyolites in association with larger amounts of trachyte and phonolite, as at Kerguelen Island (10) or as in the East Morton district of Queensland (13), or to rocks not quite so rich in SiO_2, such as the solvsbergites associated with trachytes in the Macedon district (18). Such rocks are formed, however, by the further differentiation of trachytic magmas, and are not produced by the crystallization of hypersthene and basic plagioclase. Moreover, they are a stable end-product, and not a temporary phase, which tends to revert to trachyte. On the other hand, in view of the assumption that these rocks differentiated within cupola-like protrusions above the main magma reservoir (7), some local assimilation of argillaceous and arenaceous sediments and perhaps granitic rocks is also envisaged. The numerous xenocrysts of quartz in the trachyandesites are suggestive in this respect. Where the primary magma was thoroughly undersaturated, this might have little or no apparent effect, but where, as in Victoria, the primary magma approached an intermediate composition, such assimilation might be just sufficient to produce a temporary period of local oversaturation which would pass away as more undersaturated magma was added from below. The question may legitimately be asked, why has this not happened at every centre of extrusion in Victoria? The answer may be that it has, to greater or lesser extent, but the products are not always available. The occasional norite-like xenoliths that are found in more or less "normal" lava flows, and the occasional presence of partially resorbed enstatite or hypersthene, may be regarded as indications of this tendency; although, as indicated elsewhere (10, p. 94), they may just as likely be the normal product of the intratelluric stage of differentiation of the magma.

THE DEVELOPMENT OF LIMBURGITES AND NEPHELINITES.

The origin of the small, sporadic flows of limburgite and nephelinite which are a feature of the Victorian olivine-basalt provinces presents a puzzling problem. These rocks, which consist essentially of olivine, pyroxene, and a variable amount of felspathic glass, with or without nepheline, were almost completely liquid at the time of their extrusion (intrusion), as is indicated by their fine-grained texture and the high degree of fluidity required for such "flash injections" as the monchiquite dykes of Bendigo (19). The gradational relationships which exist between these rocks, limburgite grading into olivine-nephelinite within the same flow (Jacobson, 1937, pp. 133-135), indicates a common origin for them. It may be noted also that the rare rock type, woodendite (18, p. 29), differs from the limburgites only in its relatively high potash and soda (3.2% of each).

Moreover, their small bulk, combined with their frequent association in the field with differentiated members of the olivine-basalt suites at what appear to be "centres of differentiation," suggests that they are not in themselves primary magmas but differentiates from the parent olivine-basalt magma; and that their differentiation has taken place presumably within a cupola (7).

Jacobson (12, p. 147) has suggested that such a "limburgitic liquid may be formed in the lower levels of a basaltic magma chamber only by the re-solution of some of the olivine which accumulates in this layer under gravitational control." It frequently happens, however, that olivine microphenocrysts in these rocks are idiomorphic in outline (6, p. 116; 8, p. 292). The olivine-nephelinites are suggested by Jacobson to be "limburgitic liquid" which has undergone a local enrichment in soda, possibly by gas-streaming.

Krokstrom (16) has provided a clue to another possible process by which such rocks could develop. He has shown that in some undersaturated, i.e. olivine-basalt, magmas, the plagioclase begins to crystallize before the olivine, and may even complete its crystallization before the pyroxenes commence to crystallize. As a result, the residual liquid tends to assume a pyroxenic composition. Crystallization of this liquid about the plagioclase gives rise to ophitic textures. Evidence of this tendency in Victorian basalts is found in the development of lens-like patches of ophitic pyroxene intergrown with laths of groundmass felspar, as in the Church Hill basalt at Gisborne, and elsewhere (8, p. 272). There is also plentiful evidence that in some of these rocks olivine and plagioclase have commenced to crystallize (and in some instances completed crystallizing) before the pyroxene began to crystallize. This is clearly the case in the Gisborne basalt and the iddingsite-augite-labradorite-basalts; and it is well shown where rocks of this sort have tachylytic selvedges (9). Lastly, there is the evidence provided by the occurrence of clots of olivine and "gabbro"—i.e. segregations of olivine and labradorite—that are found occasionally in the limburgites (and monchiquites) themselves, including the Bendigo monchiquites.

If as the result of intratelluric cooling, the onset of crystallization of the residual liquid, which has been enriched in pyroxene constituents in this way, is slow, what will happen? Anorthite, the most basic plagioclase, has a specific gravity of 2.74 to 2.76, and the sodic plagioclases are still lighter. The pyroxenes, on the other hand, have specific gravities ranging from 3.1 to 3.3 for enstatite to 3.5 for hedenbergite, and 3.2 to 4.1 for olivines. If the magma has a specific gravity anywhere approaching the specific gravities of these minerals that crystallize from it, it seems highly probable that the early formed plagioclase would float upwards, leaving an ultrabasic liquid behind. If the temperature of this liquid was relatively low, labradorite or even andesine might crystallize and float away, removing lime, soda, and a certain amount of potash simultaneously; whereas if the temperature of the liquid was relatively high, a correspondingly more basic plagioclase would crystallize, and remove only lime, thus leaving a relative concentration of soda and potash in the ultrabasic liquid. It may be noted in this connexion that even the true limburgites of the Newer Volcanic Province show considerable richness in both soda and potash (8, Table IX., p. 291). Presumably both these stages in differentiation might exist simultaneously in a cupola, since temperature would increase with depth, giving rise to a layer of limburgitic magma overlying and grading down into a layer of olivine-nephelinite magma, which in turn would overlie quite undifferentiated basalt magma.

Summary.

Most of the lava flows that cap the Tertiary gravels and Ordovician sediments of the Gisborne district are differentiation products of an undersaturated or olivine-basalt magma. The complex volcanic hill of Mt. Gisborne, however, is built up of a series of hypersthene-trachyandesites and hypersthene-bearing basalts, in addition to a variety of normal types. The trachyandesites and associated rocks contain numerous phenocrysts of partially resorbed hypersthene and basic plagioclase associated with phenocrysts of sanidine and anorthoclase in a still more advanced state of resorption, phenocrysts of olivine, and numerous xenocrysts of quartz, presumably derived from the intruded sediments. They present the apparent anomaly of a "tholeiitic process of differentiation" superposed on the normal (trachytic) process of differentiation. Since the parent magma from which all these rocks were derived was of a composition intermediate between oversaturation and undersaturation with respect to SiO_2, it is suggested that this local change in the

character of the differentiation may have been brought about by local assimilation of the invaded sediments making the magma saturated. Similar rock types are met with elsewhere in Victoria, but their full development in the Newer Volcanic Series is not yet known.

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